Evapotranspiration in boreal forest catchments: upscaling by process models and open GIS data

- Samuli Launiainen, Aura Salmivaara, Antti-Jussi Kieloaho, Mikko Peltoniemi, and Mingfu Guan

contact: samuli.launiainen@luke.fi

Presentation available at:
https://github.com/LukeEcomod/EGU2018

Luke
NATURAL RESOURCES INSTITUTE FINLAND

Background

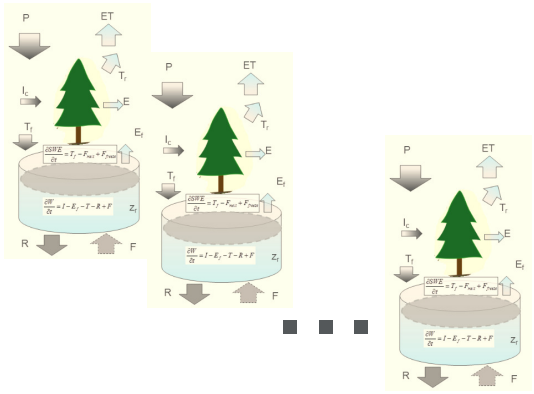
- Boreal mixed coniferous forests cover ~80% of land area in Finland
- Forest management creates mosaic landscape
- Climate (60 … 70 N)
  - Annual mean T & precip from between +5 ‘C / 750mm in the south to -2 ‘C / 450 mm in the north
- Why actual ET and its spatial variability?
  - Soil moisture & biogeochemical cycles, growth and climate feedback
  - Improved description of ET will reduce uncertainties in catchment models

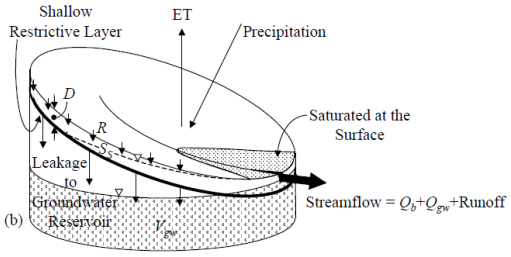
Objectives:

1) Develop generic daily stand-level ET model
   - validate against eddy-covariance data
2) Upscale to landscape scale using open data
   - evaluate using annual ET from catchment water balance

Semi-distributed catchment model

Catchment → (n x m) grid of buckets





+ TOPMODEL for streamflow generation, returnflow and saturated area

Launiainen et al. 2018, in prep.

INPUT GRIDS:

- Conifer & deciduous LAI, tree height
- Soil map
- Catchment boundaries
- Topografic wetness index TWI

DAILY FORCING

- Precip, SW radiation, temperature, RH (or VPD), wind speed

DAILY GRID-OUTPUTS:

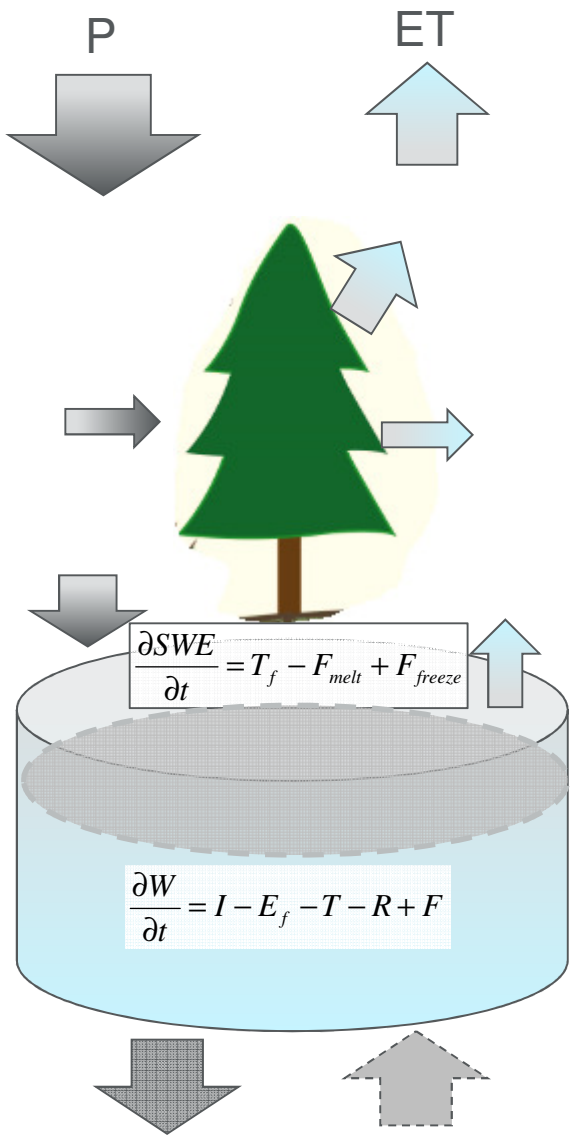
- ET & components
- Snow water equivalent
- Organic layer & root zone moisture
- Drainage from root zone
- Saturation deficit (→ proxy of water table)
- Returnflow & dynamics of saturated area

CATCHMENT OUTLET

- Streamflow

https://github.com/LukeEcomod/EGU2018

Luke
NATURAL RESOURCES
INSTITUTE FINLAND



Three-source Penman-Monteith

- Evaporation (sublimation) of canopy intercepted rain (snow)
- Canopy transpiration
- Evaporation from ground

$$E_i = \frac{1}{L_v} \frac{\Delta(R_{n,i}) + \rho_a c_p G_{a,i} D}{\Delta + \gamma(1 + G_{a,i}/G_i)}$$

Temperature-index snow model

Two-layer bucket model

- Organic layer acts as interception storage: evaporation
- Bottom layer root zone: root uptake
- Drainage and returnflow

https://github.com/LukeEcomod/EGU2018

Luke NATURAL RESOURCES INSTITUTE FINLAND

Leaf to canopy stomatal conductance

$$g_s = g_o + 1.6\left(1 + \frac{g_1}{\sqrt{D}}\right)\frac{A}{C_a}$$

Medlyn et al. 2011
'USO'

scale-analysis & hyperbolic light-response

$$g_s \sim \frac{1.6(1+g_1)}{C_a}\frac{A_{max}PAR}{PAR+b}\frac{1}{\sqrt{D}}$$

g_{sref}

Exponential PAR within canopy

$$PAR(L) = PAR_o exp(-k_p L)$$

- A net photosynthesis
- g_1 depends on water use strategy
- g_{sref} light-saturated stomatal conductance at D = 1 kPa & const C_a

- Scots pine: g_{sref} ~2.5 mm/s (2.2 – 2.8), b ~30 – 50 Wm^{-2}
- Birch, aspen ~4.0 – 4.5 mm/s
- k_p ~0.6

$$G_c = \frac{g_{sref}}{k_p} ln\left(\frac{PAR+b}{PAR \times exp(-k_p LAI) + b/k_p}\right) \times \frac{1}{\sqrt{D}} \times f(\theta_{REW}) \times f_{CO2} \times f_S.$$

plant traits

Leaf → canopy

soil moisture

atm. CO2

phenology

Medlyn et al, 2011.
Global Change Biol. 17, 2134-2144

Parameterization of the 3-source model

- Parameters mainly from literature
- 3 parameters calibrated using data from a single flux site, Hyytiälä, in Southern Finland
- 1 for ground evaporation:
  - multi-layer SVAT –model APES
  - sub-canopy EC data
- 1 for transpiration
  - g_{sref} from leaf gas exchange
  - check against EC data
- 1 for interception of rainfall:
  - capacity = w x LAI, using throughfall data

APES: Launiainen et al. 2015 Ecol. Mod

https://github.com/LukeEcomod/EGU2018

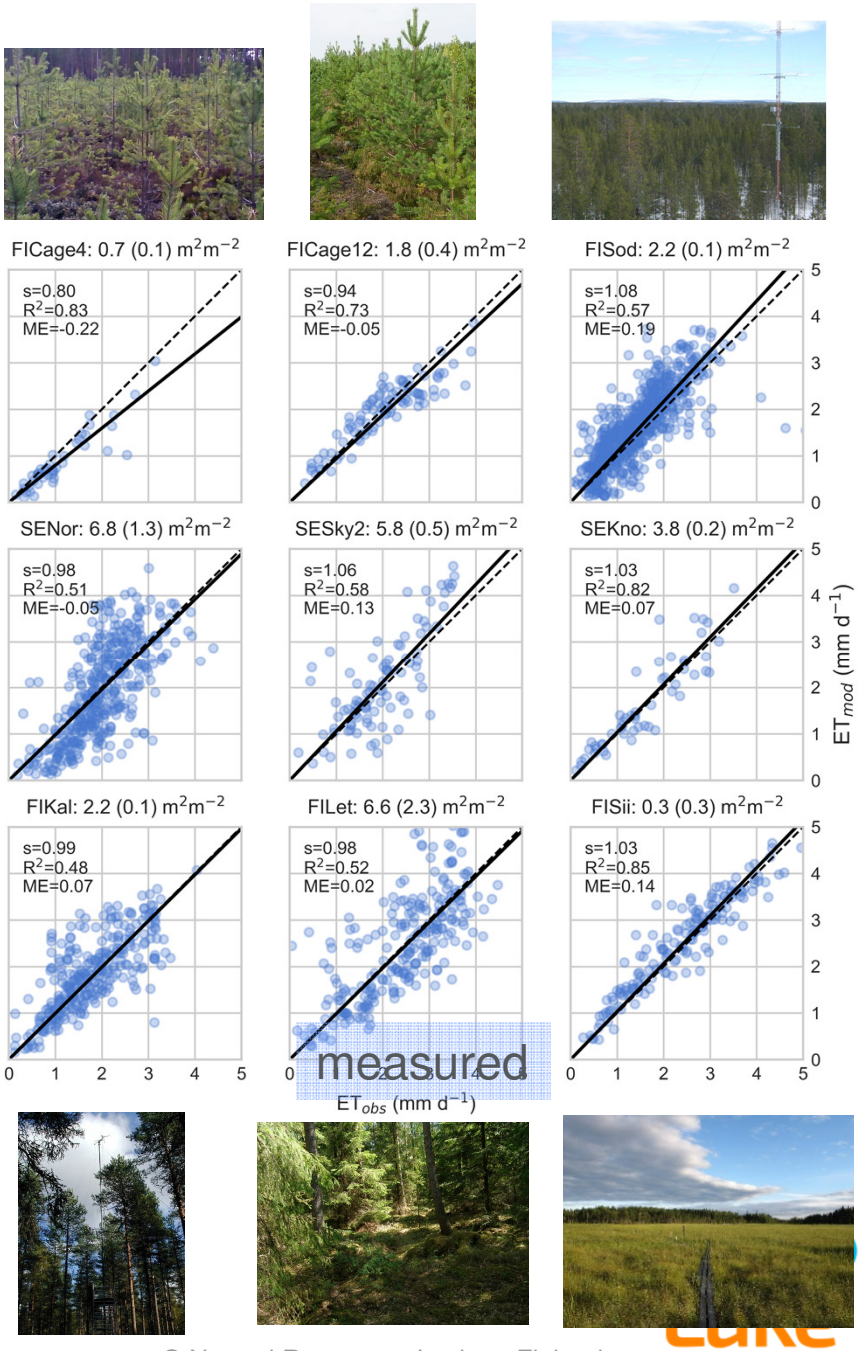
Luke NATURAL RESOURCES INSTITUTE FINLAND

Site scale validation

- 9 EC sites from Finland & Sweden, 60 N to 68 N
- LAI (1-sided) from 0.2 to 6.8 m^2m^{-2}
- Pristine peatland … dense managed forests

- Daily ET
  - dry-canopy conditions
  - Growing season (May-Oct)

- Independent comparison



https://github.com/LukeEcomod/EGU2018

NATURAL RESOURCES INSTITUTE FINLAND

Multi-source National Forest Inventory (16 X 16 m)

1km

1,4km

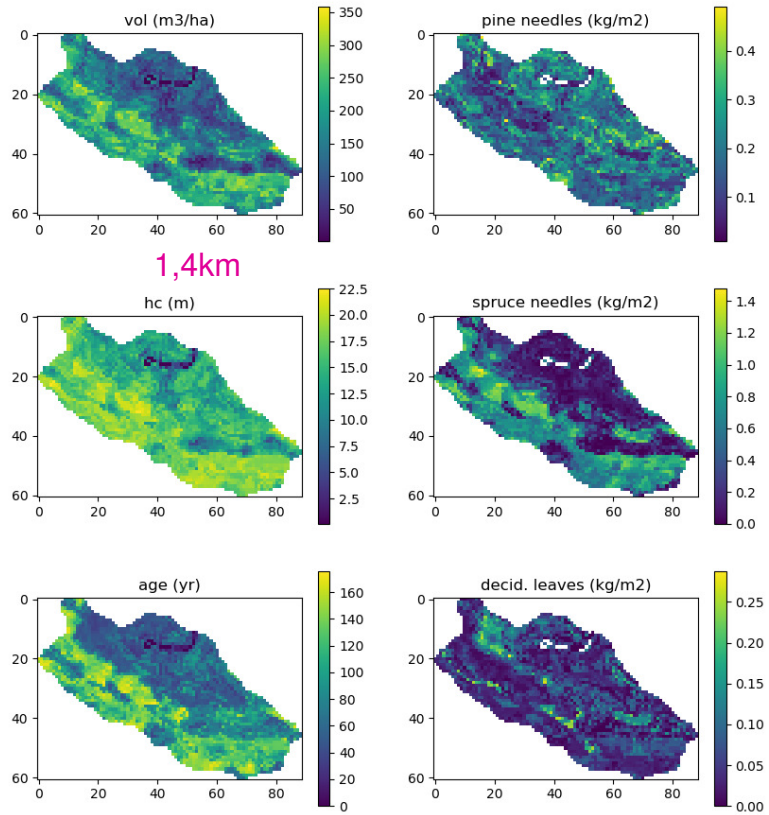


Table 4.3: The estimated raster themes.

Theme
Biomass, spruce, living branches 2013 (10 kg/ha)
Biomass, spruce, stem residual 2013 (10 kg/ha)
Biomass, spruce, roots, d > 1 cm 2013 (10 kg/ha)
Biomass, spruce, stump 2013 (10 kg/ha)
Biomass, spruce, dead branches 2013 (10 kg/ha)
Biomass, spruce, stem and bark 2013 (10 kg/ha)
Biomass, spruce, foliage 2013 (10 kg/ha)
Biomass, broad-leaved trees, living branches 2013 (10 kg/ha)
Biomass, broad-leaved trees, stem residual 2013 (10 kg/ha)
Biomass, broad-leaved trees, roots, d > 1 cm 2013 (10 kg/ha)
Biomass, broad-leaved trees, stump 2013 (10 kg/ha)
Biomass, broad-leaved trees, dead branches 2013 (10 kg/ha)
Biomass, broad-leaved trees, stem and bark 2013 (10 kg/ha)
Biomass, broad-leaved trees, foliage 2013 (10 kg/ha)
Biomass, pine, living branches 2013 (10 kg/ha)
Biomass, pine, stem residual 2013 (10 kg/ha)
Biomass, pine, roots, d > 1 cm 2013 (10 kg/ha)
Biomass, pine, stump 2013 (10 kg/ha)
Biomass, pine, dead branches 2013 (10 kg/ha)
Biomass, pine, stem and bark 2013 (10 kg/ha)
Biomass, pine, foliage 2013 (10 kg/ha)
Site main class 2013 (1–4)
Site fertility class 2013 (1–8)
Land class 2013 (1–3)
Stand age 2013 (year)
Stand mean diameter of 2013 (cm)
Stand mean height 2013 (dm)
Canopy cover 2013 (%)
Canopy cover of broad-leaved trees 2013 (%)
Stand basal area 2013 (m^2/ha)
Data source index, MSNFI 2013
Volume, birch 2013 (m^3/ha)
Volume, birch pulpwood 2013 (m^3/ha)
Volume, birch saw timber 2013 (m^3/ha)
Volume, spruce 2013 (m^3/ha)
Volume, spruce pulpwood 2013 (m^3/ha)
Volume, spruce saw timber 2013 (m^3/ha)
Volume, other broad-leaved trees 2013 (m^3/ha)
Volume, other broad-leaved trees pulpwood 2013 (m^3/ha)
Volume, other broad-leaved trees saw timber 2013 (m^3/ha)
Volume, pine 2013 (m^3/ha)
Volume, pine pulpwood 2013 (m^3/ha)
Volume, pine saw timber 2013 (m^3/ha)
Volume, the growing stock 2013 (m^3/ha)

>80 0000 forest inventory plots + Landsat & Resourcesat images, DEM, topographic database & kNN -interpolation

Open data, 3 year update interval

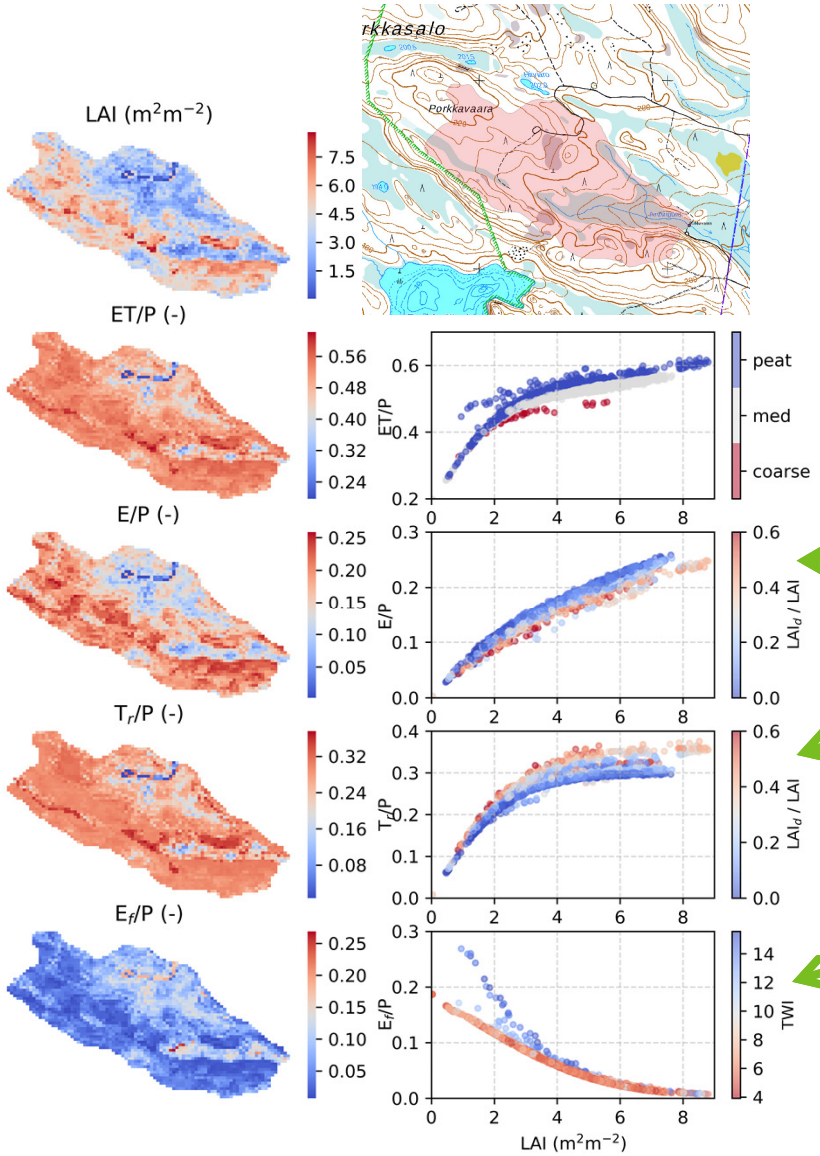
Comparison with MODIS LAI: Härkönen et al 2015 Bor. Env. Res. 20: 181–195

http://kartta.luke.fi/index-en.html

https://github.com/LukeEcomod/EGU2018

Luke
NATURAL RESOURCES INSTITUTE FINLAND

Spatial variability within catchment



Porkkavaara catchment, Eastern Finland, 64ha, 16x16m grid

ET / P

- LAI –relationship non-linear; inflection point at LAI 2 to 3 m^2m^{-2}

Interception

- Capacity ~ a x LAI
- Snow interception

Transpiration

- Saturates due to light limitations
- Higher where deciduous dominant
- Drought stress at coarse soils

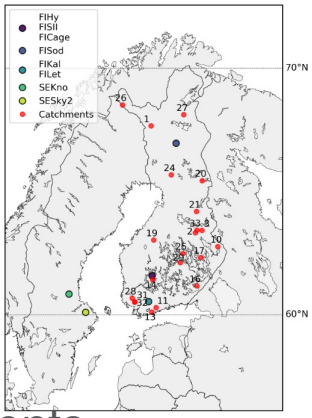
Evaporation from ground

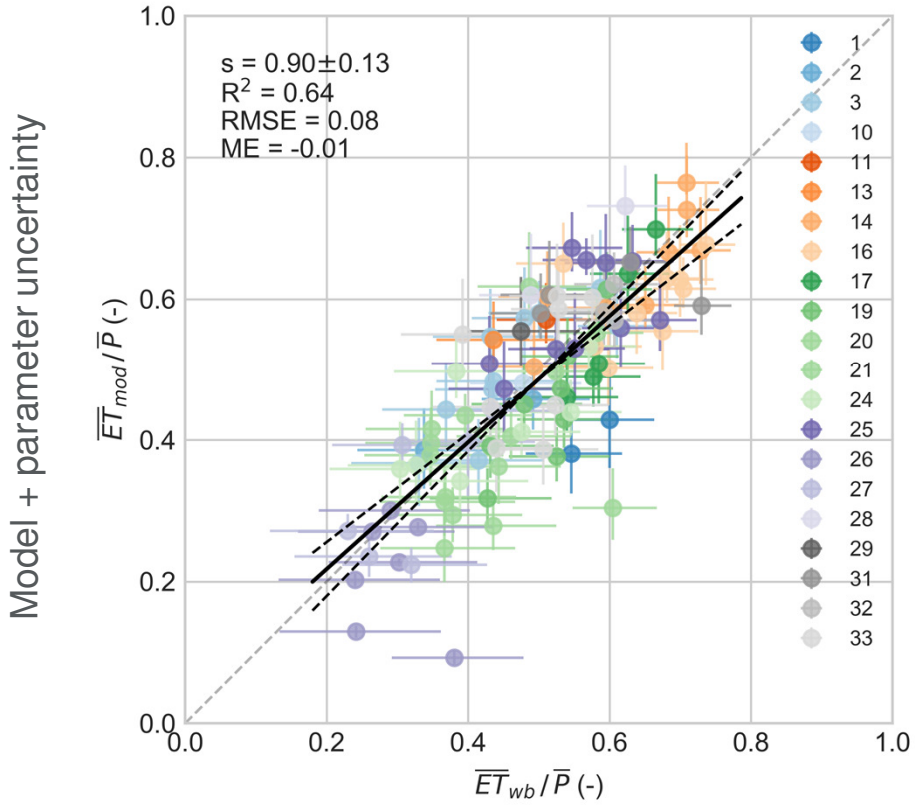
- available energy
- Gridcells with high TWI receive returnflow & behave as wet surfaces

https://github.com/LukeEcomod/EGU2018

Luke NATURAL RESOURCES INSTITUTE FINLAND

Annual evapotranspiration ratio





Catchment water balance ET = P – Q

- 21 headwater catchments over Finland. Streamflow data 1 - 10 yr / catchment
- Independent comparison
- Across-catchment variability primarily due to north-south gradient:
  - E_{pot} / P
  - Length of snow-cover & annual snowfall
  - LAI

https://github.com/LukeEcomod/EGU2018

Luke NATURAL RESOURCES INSTITUTE FINLAND

Take home!

- Daily ET can be predicted with simple scheme with no site / catchment-specific calibration
- A three-source model seems as a good compromise
- Multi-source NFI data as a resource for hydrologic & biogeochemical modeling

- Codes (Python 2.7/3.x) + data available by request
- Contact: samuli.launiainen@luke.fi

https://github.com/LukeEcomod/EGU2018

Luke NATURAL RESOURCES INSTITUTE FINLAND

Thank you!

contact: samuli.launiainen@luke.fi

Presentation available at:
https://github.com/LukeEcomod/EGU2018

Luke
NATURAL RESOURCES
INSTITUTE FINLAND